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Estimation of Arterial Resistance and Compliance in Humans

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***Abstract*— This paper demonstrates an objective method to measure arterial resistance (R), inertance (L) and compliance (C) in humans from arterial vascular impedance. *Clinical Relevance*—Dynamic measurements of arterial resistance and compliance during drug interventions can improve the treatment decisions.**

I. INTRODUCTION

Estimation of changes in arterial resistance and compliance during a drug intervention can give insights on its differential action on resistance versus compliance vessels. The aim of this study is to develop an objective method of quantifying arterial resistance and compliance from simultaneous intraarterial pressure (from radial artery) and Doppler based volume flow recordings (from distal end of the radial artery) in an ICU setting. Blood flow in arteries can be modelled as a linearized lumped electrical circuit (three-element Windkessel) [1]. Laplace domain network analysis of the model yields vascular impedance, Z as per the equation,

$$\omega^2[(R_1R_2C+L)^2-2(R_1+R_2)(R_2LC)]+(R_1+R_2)^2+\omega^4(R_2LC)^2-\omega^2Z^2(R_2C)^2=Z^2 \quad (1)$$

Four impedance values from impedance spectra yield four equations that can be resolved for estimating $R_1, R_2\ L, C$.

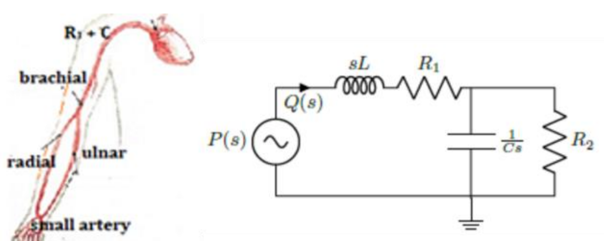

Fig.1. Lumped model of arterial tree

II. METHODS

This study was approved by the IRB, CMC Vellore (*IRB no: 9930, 17/02/2016*). A stable ICU patient with arterial pressure cannulae already placed as standard of care was recruited after obtaining informed consent. Intra-arterial pressures from the radial artery, its Doppler images and the Doppler audio signal were captured synchronously on a multi-channel validated data acquisition system (CMCdaq). The pressures and the audio were sampled at 4kHz (> twice the doppler-shift frequency). The video of Doppler imaging of the radial artery was recorded on CMCdaq using an externally mounted camera at a fixed rate of 30 fps.

***A. Calculating arterial vascular impedance*:** Arterial vascular impedance, $\boldsymbol{Z[k]}$ is the ratio of intra-arterial pressures to the volume blood flow in the frequency domain [2]: $\boldsymbol{Z[k]=\frac{P[k]}{Q[k]}}$, where $\boldsymbol{P[k]}$ is the Discrete Fourier Transform (DFT) of the intra-arterial pressure *p[n]*, and $\boldsymbol{Q[k]}$ is the DFT of volume-flow *q[n]*. Volume flow is calculated as the product of blood flow velocity multiplied by the area of cross-section at the site of measurement. $\boldsymbol{Z[k]}$ is computed as follows:

1. Compute DFT of the pressure signal, P[k].
2. Compute frame-by-frame volume blood flow, *q[n]*:
   2.1. Compute radial artery cross-sectional area per frame, *a[n]*, *n*=frame no.
   2.2. Compute linear flow velocity per frame, $v[n]=\frac{c.f_D}{2f\cos\theta}$, *where* f_D is the mean doppler-shift frequency per frame, f is the probe transmission frequency (8MHz), c is the velocity of sound in blood (1580 m/s), and θ is the insonation angle (45°).
   2.3. Volume flow, *q[n]= a[n] * v[n]*
3. $Z[k]=\frac{P[k]}{Q[k]}$; resolve for $R_1, R_2\ L, C$ using equation (1).

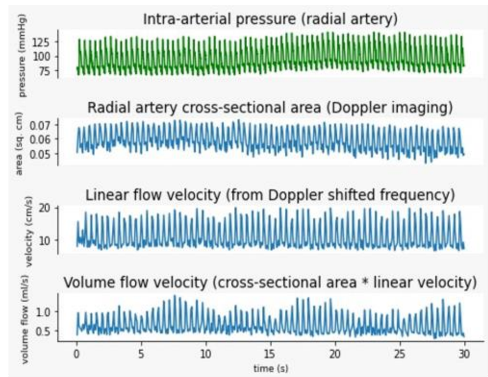

Fig.2. Synchronous data collection in CMCdaq & volume flow calculation

III. RESULTS & DISCUSSION

Figure 2. shows the time-domain signals for arterial pressure (mmHg) and volume flow (ml/s) collected from one human subject in Surgical ICU. Vascular impedance is calculated as the ratio of harmonic terms of pressure to the corresponding harmonic terms of volume flow as shown in Figure 3. Division-by-zero error is avoided in impedance calculation by considering only the non-zero peaks of the spectrum. Solving for the four lumped parameters, we get, R_1= *243×10⁹ Pa. m⁻³.s*, R_2=*950×10⁹ Pa. m⁻³.s*, *L=18.8×10⁹ Pa. m⁻³.s²*, *C= 6.6×10⁻¹⁴ Pa⁻¹.m³*.

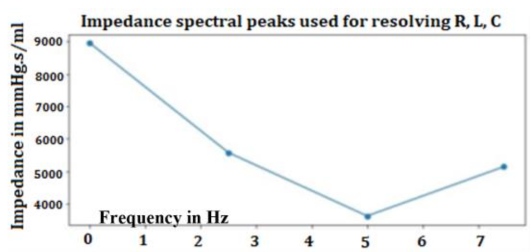

Fig. 3. Four samples from Impedance spectra

This is a proof-of-concept paper discussing the feasibility of assessing any change in the arterial resistance or compliance in an ICU setting during a drug intervention. The study also demonstrates a Doppler based method to measure volume blood flow in ml/s when the conventional methods use linear velocity.

REFERENCES

[1] S. R. Devasahayam, *Signals and systems in biomedical engineering: Physiological systems modeling and signal processing: Third edition*. 2019.

[2] W. W. Nichols and M. F. O'Rourke, *McDonalds's blood flow in arteries : theoretical, experimental and clinical principles*. London: Edward Arnold, 1998.